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Improvement in solar cell efficiency via addition of luminescent down-shifting phosphors as spectral converters

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1. Abstract

The yttrium aluminium garnet (YAG: Ce) phosphor on the surface of GaAs solar cell are demonstrated to have promising potential for efficient solar spectrum utilization. We combine GaAs solar cell major used on concentrating process and YAG:Ce phosphor that make an approximately 2.2-fold enhancement in power conversion efficiency and up to 20.97 mA/cm^2 in short-circuit current density. This experiments conclude that the phosphor particles not only play as luminescent downshifting centers in the ultraviolet region but also serve as an anti-reflection coating for enhancing the light absorption in the overall spectral response of external quantum efficiency.

2. Introduction

As for a solar cell, it's crucial to utilize full-band solar spectrum. GaAs based solar cell with direct bandgap and high stability could absorb solar spectrum before 900 nm. For the single junction, it has recently achieved PCEs of 28.8%.[1] However, UV segment with shallow absorption depth in GaAs formed electron-hole pair close to the surface of semiconductor and furthermore, according to the characteristic of GaAs, the surface recombination is strong.[2] Considering the reason above, the utilization in ultraviolet region is poor.

This problem can be mitigated using certain substances to transform high-energy photons into lower-energy photons also named luminescent downshifting (LDS). Therefore, more electron-hole pairs can be created per incident photon, generating a higher short circuit current density (Jsc).

In this study, we combine the single junction GaAs solar cells and the YAG phosphor to enhance the solar cell efficiency. Phosphors can absorb UV photons and then downshift high-energy photons into visible, allowing them to penetrate deeper into bulk semiconductors, thus enabling the generated electron-hole pairs to be collected more effectively. Moreover, because the phosphor is a well-known material in LED package and the fabrication technology are developed very long time, the phosphors have higher quantum yield and lower cost than the quantum dots.

3. Experiments

Fig. 1. shows a schematic plot of the fabrication process with YAG: Ce phosphor spraying on the single junction GaAs solar cell by using power spray machine. The single junction GaAs solar cell was grown on Si-doped n-type GaAs substrate by metal-organic chemical vapor deposition (MOCVD).[3] The back-side n-contact in the proposed design was formed by evaporating AuGe(250Å)/Au(5000Å), whereas the front p-contact consisted of Ti(250Å)/Pt(250Å)/Au(5000Å). The shadow loss of the front strip contacts was 3.5%, and area of the cells was 1 cm2. The pulsed spray (PS) coating method was used to spray the phosphor layers. A flexible PDMS film was pasted onto the surface of GaAs solar cells before spray phosphor to avoid the contact of solar cells with phosphor powders elevating series resistance.

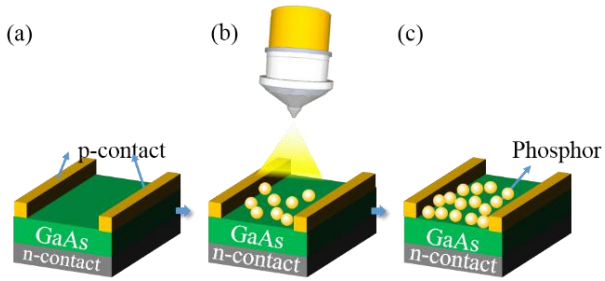

Fig. 1. A schematic plot of the fabricated single-junction GaAs solar cell with flexible PDMS and silicate phosphor.

Fig. 2. shows that Y2A5O12: Ce phosphors were excited at 450 nm and emission at 550 nm (red line). The PLE spectrum was measured at a fixed detection wavelength of 550 nm. The spectrum shows two peak resonance at 350 and 450 nm.

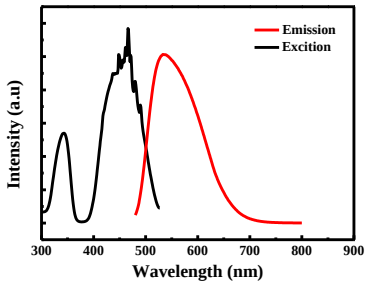

Fig. 2. The PLE spectrum of silicate phosphor was taken at the maximum of PL intensity (550 nm). For the PL spectrum, the sample was excited by a light beam with 450 nm.

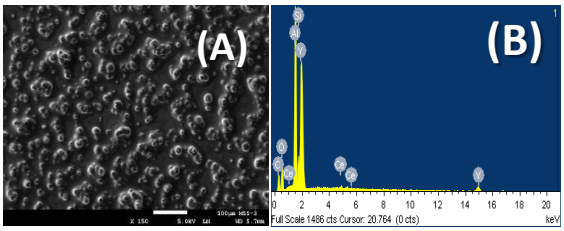

Fig. 3. (a) is the scanning electron microscope (SEM) image of YAG: Ce covering by Pt. Fig. 3. (b) The energy dispersive spectrometer (EDS) of YAG: Ce was taken by a JEOL JEM-2100F system.

Fig. 3(a) shows the scanning electron microscope (SEM) image of phosphor spraying on the glass sample by the pulsed spray coating method at the same time. The energy dispersive spectrometer (EDS) of the YAG: Ce phosphor is also displayed in the Fig. 3(b). The peaks at Ce, Al and Y match well with the standard EDS data of YAG: Ce to further identify the element on glass.

4. Result and Discussion

Fig. 4. shows clearly that the pasted PDMS solar cell offer a superior anti-reflective property at wavelengths comparison with the reference cells because of the refractive index matched. By contrast, the phosphor-coated sample has low reflectance at around 350 nm and 450 nm region than the pasted PDMS solar cell and a peak centered at 550 nm, which is the emission wavelength of YAG: Ce phosphor. This result agrees with the PLE and PL spectra. The reduction of reflectance in the short wavelength spectrum means that the high-energy photons can absorb by the phosphor particles and downshift to the wavelength of 550 nm.

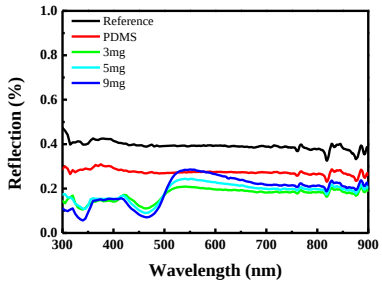

Fig. 4. The measured reflectance spectra for bare, PDMS coated, and phosphor-coated single junction GaAs solar cells.

Fig. 5 shows the photovoltaic current density-voltage (J–V) characteristics of a GaAs solar cell with and without sprayed phosphors. The short-circuit current density (Jsc) of the sprayed phosphors sample can reach 20.97 mA/cm2 and its power conversion efficiency increases from 13.99% to 15.99%, corresponding to a 14.3% enhancement compared to the device without anti-reflection coating (Reference). Moreover, open-circuit voltages (Voc) of these devices show no degradation, and the change in fill-factor (FF) is negligible.

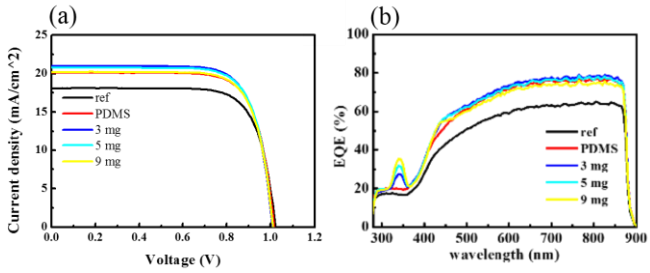

Fig. 5 (a) The photovoltaic J–V characteristics of GaAs solar cells for different type sample. Fig5 (b). The measured external quantum efficiency results of GaAs solar cells for different type sample.

In order to confirm the downshifting capability of phosphor in GaAs solar cells, the spectral response of EQE was measured to analyze. The EQE of pasted PDMS device reveals broad-band enhancement from 300 to 900 nm which is attributed to a gradient of refractive index change, similar to that of an anti-reflection coating. Then the EQE has obviously enhancement in 350 nm and 450 nm as the concentration increase (not shown here). Moreover, the sprayed phosphors sample enhanced not only at the long wavelength by the anti-reflection effect like the pasted PDMS film sample but also at the ultraviolet region of spectral response by the luminescent downshifting effect. The enhancement factor is defined as EQE/EQE reference. According to the EQE measurement, a maximum 2.2-fold enhancement can be achieved in 350 nm.

5. Conclusion

In conclusion, we successfully combine YAG: Ce phosphors with GaAs solar cell to form a highly efficient hybrid solar cell. The phosphor is not only stable but also high quantum yield, so that is common used in the application of white light LED package. It is noticeable that the phosphor can significantly enhance power conversion efficiency under air mass 1.5 global illuminations. The main mechanism of the enhancement can be attributed to luminescent downshifting and antireflection. Consequently, the overall power conversion efficiency is enhanced by 14.3% and 3.2%, when compared to the reference cell and the cell with PDMS film, respectively.

References

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